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Perfusion Techniques Toward Bloodless Pediatric Open Heart Surgery

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Abstract: There continues to be evidence regarding the negative impact of blood transfusion on morbidity and mortality in the adult literature, including infection risk, increased hospital and intensive care length of stay, and costs. More effort has been put into reducing the use of blood components in adult surgical centers but blood transfusions continue to be used frequently in pediatric centers. From 2002 through 2005, we embarked on a mission of reduced prime volume in an effort toward bloodless cardiac surgery to meet the needs of the Jehovah's Witness patient. The same bloodless surgical and perfusion techniques were applied to all patients undergoing cardiopulmonary bypass beginning in 2006. Circuit size was minimized and acute normovolemic hemodilution (ANH) was considered and attempted more often, especially if a re-operation. Retrograde arterial prime (RAP) and venous antegrade prime (VAP), dilutional or balanced ultrafiltration during cardiopulmonary bypass, modified arteriovenous ultrafiltration post bypass, and cell salvage of remaining circuit contents after flushing with crystalloid were recorded. ANH, RAP, and VAP, separately or in combination, were used less than 1% of the time prior to 2006. From 2006–2008 ANH was performed on 42% of the patients and RAP/VAP was performed on 70% of the patients. From 2006–2008, 43% (287 of 662) of the open heart surgeries were performed bloodless in the operating room versus 30% (193 of 633) from 2003–2005. Bloodless surgery more than doubled for the 0–6, 6–15, and 15–20 kg groups from 3.5%, 23%, and 23% respectively in 2003–2005 to 9%, 44%, and 58%, respectively in 2006–2008. With the cooperation of the entire cardiac surgical team, bloodless open heart surgery is achievable in a pediatric cardiac surgical center, including neonates. **Keywords:** pediatric cardiopulmonary bypass, bloodless, transfusion, Jehovah's Witness. *JECT. 2010;42:122–127*

There continues to be evidence regarding the negative impact of blood transfusion on morbidity and mortality in the adult literature, including infection risk, increased hospital and intensive care length of stay, and costs (1–3). More effort has been put into reducing the use of blood components in adult surgical centers, but blood transfusions continue to be used frequently in pediatric centers (1,2).

Cardiac surgical repair of congenital heart defects in pediatric patients undergoing cardiopulmonary bypass (CPB) has induced up to a 300% hemodilutional effect due to circuit prime volumes (4,5). The concept of bloodless surgery is not new in pediatric cardiac surgery, although the vast majority of experience has been gained with patients of Jehovah's Witness faith (6,7). Recently there have been a number of centers reporting the ability to manage pediatric, and specifically neonatal, patients without the use of blood, however these tend to be isolated examples or small series of patients (8–13).

In late 2002 we started aggressively reducing and miniaturizing circuit components to decrease the overall circuit prime and resulting hemodilution. We started exploring techniques toward a bloodless surgical program to meet the needs of an increasing number of patients of Jehovah's Witness faith. We discovered through this process that we were able to successfully offer bloodless cardiac surgery to this group of patients with low morbidity and mortality. In early 2006 we applied this bloodless strategy to all congenital cardiac surgery patients undergoing CPB.

The purpose of this study was to retrospectively evaluate the use of blood conservation techniques and the ability to perform bloodless, open-heart cardiac surgery in a tertiary pediatric cardiac surgical center.

METHODS

After approval by the institutional review board, all patients undergoing CPB from January 2003 through December 2008 were retrospectively reviewed. The patients

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were sorted into time periods. The first time period consisted of all CPB patients that had surgery from January 2003 through December 2005, where aggressive blood management techniques were primarily reserved for patients of Jehovah's Witness faith. The second time period consisted of all CPB patients from January 2006 through December 2008 where all patients received the same, aggressive blood management techniques. Patients were further sorted into weight groups based on circuit size, for analysis purposes, of 0–6 kg, 6–15 kg, 15–20 kg, 20–40 kg, 40–80 kg, and >80 kg.

Patient weight, height, date of surgery, red blood cell (RBC) use in the operating room (OR), acute normovolemic hemodilution (ANH), retrograde arterial prime (RAP), venous antegrade prime (VAP), and prime volume were recorded. Circuit selection was based on both the procedure and a target calculated blood flow rate of 2.2 L/min/m^2. Arterial-venous loop selection was from the following: 1/8″ × 3/16″, 5/32″ × 1/4″, 3/16″ × 1/4″, 1/4″ × 3/8″, 3/8″ × 3/8″, and 3/8″ × 1/2″. Suckers were 1/8, 3/16, or 1/4″ depending on the particular circuit selected. All tubing was coated, where possible, with Terumo X coating™ (Terumo Cardiovascular, Ann Arbor, MI) down to 3/16″. Oxygenators were selected from the following: Terumo RX05®/FX05®, Terumo SX10® or RX15®, or Terumo SX18® or RX25® (Terumo Cardiovascular, Ann Arbor, MI) or Maquet Quadrox (Maquet Cardiopulmonary, Hirrlingen, Germany), depending on patient size. No arterial line filter (ALF) was used for the two smallest circuits: 1/8″ × 3/16″ and 5/32″ × 1/4″; otherwise a Terumo Capiox® CXAF02, 40 mL prime, CXAF200X, 200 mL prime, or CXAF125, 125 mL prime ALF (Terumo Cardiovascular, Ann Arbor, MI) was used. CPB was performed with the Maquet HL-20 (Maquet Cardiopulmonary, Hirrlingen, Germany) using roller pumps for most procedures.

Continuous arterial blood gas and venous saturation/hematocrit monitoring with the CDI 500 (Terumo Cardiovascular, Ann Arbor, MI) was used on all procedures. All patients had cerebral saturation monitoring with the INVOS 5100 B or C monitor (Somanetics Corporation, Troy, MI). Arterial and venous blood gas, electrolyte, glucose, lactate, and hematocrit (Hct) were measured with the I-Stat® (Abbott Point of Care, Princeton, NJ). Anticoagulation was monitored with the Hemochron Jr® (ITC, Edison, NJ) and Medtronic Heparin Management System® (Medtronic, Inc., Minneapolis, MN). Cell salvage with the Fresenius CATS (Terumo Cardiovascular, Ann Arbor, MI) continuous autotransfusion system was used on all procedures.

Perioperative acute normovolemic hemodilution was considered on all patients starting in 2006. After sampling and documenting a baseline Hct in the OR of ≥30%, autologous blood was removed through the arterial or central line, as tolerated, and replaced with .9% normal saline, lactated Ringer's solution, Normosol®-R (Hospira, Lake Forest, IL), or plasma protein fraction at the discretion of the anesthesiologist. Autologous blood was anticoagulated with 10 mL of Anticoagulant Citrate Dextrose Solution, Solution A (ACD-A), per 100 mL of autologous blood. Autologous blood was labeled per institutional standard, stored at room temperature, and transfused by anesthesia post-protamine administration unless needed during bypass secondary to low Hct and/or venous saturation.

After arterial cannula insertion, RAP was initiated by controlled aspiration on the CPB arterial line (retrograde) into a syringe or transfer bag as previously describe by Rousou et al. (14). Crystalloid prime solution is displaced with the patient's blood via the arterial manifold purge port back as far as the oxygenator in our two smallest circuits, or to the ALF in the larger circuits. VAP began after a venous cannula was inserted and connected to the venous line. Two clamps were placed on the venous line. One clamp was placed across the venous line at approximately 75% occlusion. A second, fully occlusive clamp, was intermittently opened and closed which allowed the crystalloid prime to drain from the venous line and was displaced by the patient's blood. The crystalloid prime was simultaneously pumped out of the reservoir into a syringe or blood transfer bag. This process continued until the patient's blood had replaced the crystalloid prime in both the oxygenator and ALF, if present, or as long as tolerated.

Trasylol (Bayer Healthcare Pharmaceuticals, Wayne, NJ) was used on all patients through April 2008. Starting in May 2008, Tranexamic acid was used at 100 mg/kg load to the patient and 100 mg/kg added to the pump prime, along with a steroid, dexamethasone, 1 mg/100 mL of pump prime to a maximum of 10 mg. All drugs were added to the bypass circuit after completion of RAP and VAP.

Target Hct on CPB was ≥20% with notification of the surgeon if lower. Blood was only administered after consultation with the surgeon. If RBCs were used, they were first mixed with at least 500 mL Normosol®-R and washed with the cell saver. Over 95% of all patients underwent arterial-venous modified ultrafiltration (MUF) and conventional ultrafiltration or dilutional ultrafiltration during CPB. Upon completion of MUF all circuits were flushed with one liter of Normosol®-R to the cell saver for processing.

RESULTS

From January 2003 through December 2008 there were 1293 procedures requiring CPB, 633 between 2003 and 2005, and 660 between 2006 and 2008. Table 1 shows the number of procedures by weight category.

Prior to 2006 ANH was used on less than 1% of all patients. ANH use increased over the 3 year period from 2006–2008, and was used on 42% of all patients and 12% of patients 0–6 kg (Figure 1) increasing from 6% in this weight group in 2006 to 16.7% in 2008. For the patients greater than 20 kg, ANH use averaged over 60%.

RAP/VAP was used on less than 1% of patients prior to 2006. For the three year period 2006–2008, RAP/VAP averaged 70% for all patients and 38% of patients 0–6 kg, increasing from 28–55% over the 3 year period (Figure 2). For the patients greater than 6 kg, RAP/VAP averaged over 80% for each of the weight groups.

Figure 3 shows the bloodless surgical cases for the 6 year period 2003–2008. Bloodless surgery was performed on 30% of all patients from 2003–2005 and 43% of patients from 2006–2008. Bloodless surgery more than doubled for the 0–6, 6–15, and 15–20 kg groups from 3.5%, 23%, and 23% respectively in 2003–2005 to 9%, 44%, and 58%, respectively in 2006–2008.

DISCUSSION

There is essentially no literature available describing the results of a programmatic approach to bloodless cardiac surgery in a pediatric center. Through our early development stage of a program of bloodless techniques for the Jehovah's Witness patient, we found this group of patients experienced low morbidity and mortality, which motivated us to explore these techniques for all patients.

Table 1. Patient number by weight groups.

Weight Range (kg)	2003–2005	2006–2008
0–6	227	227
6–15	210	227
15–20	30	33
20–40	43	45
40–80	90	96
>80	33	32
Overall	633	660

Ootaki et al., in a prospective, non-continuous study of 75 pediatric patients undergoing cardiac surgery using a criteria-driven transfusion protocol, achieved 70% transfusion free procedures (9). Mean weight of the transfusion free group was 24.6 ± 13.4 kg. In our series of patients from 2006–2008, we were able to achieve 58% of the CPB patients transfusion free in the 15–20 kg weight range and 78% in the 20–40 kg range.

Durandy did a retrospective review of transfusion of 259 consecutive patients weighing <15 kg that underwent open-heart surgery. In the group of patients weighing less than 6 kg, they were unable to accomplish bloodless procedures. However, of those receiving blood, only 4% required greater than one unit of RBCs (15). Our similar weight group of 0–6 kg, with 185 mL prime volume, which included cardioplegia and ultrafilter, achieved bloodless surgery in 9%, and 45% for patients 6–15 kg. While not reported in this study, we would subjectively concur with Durandy, that when blood is administered in these patients, there is a greater Hct increase with a single unit of RBCs. This increase is accomplished by using smaller size circuits and results in overall less blood transfusion when needed.

Boettcher et al. and Ging et al., among others, have written single case reports of bloodless surgical techniques on neonates and infants (8,12). Similarly, we have

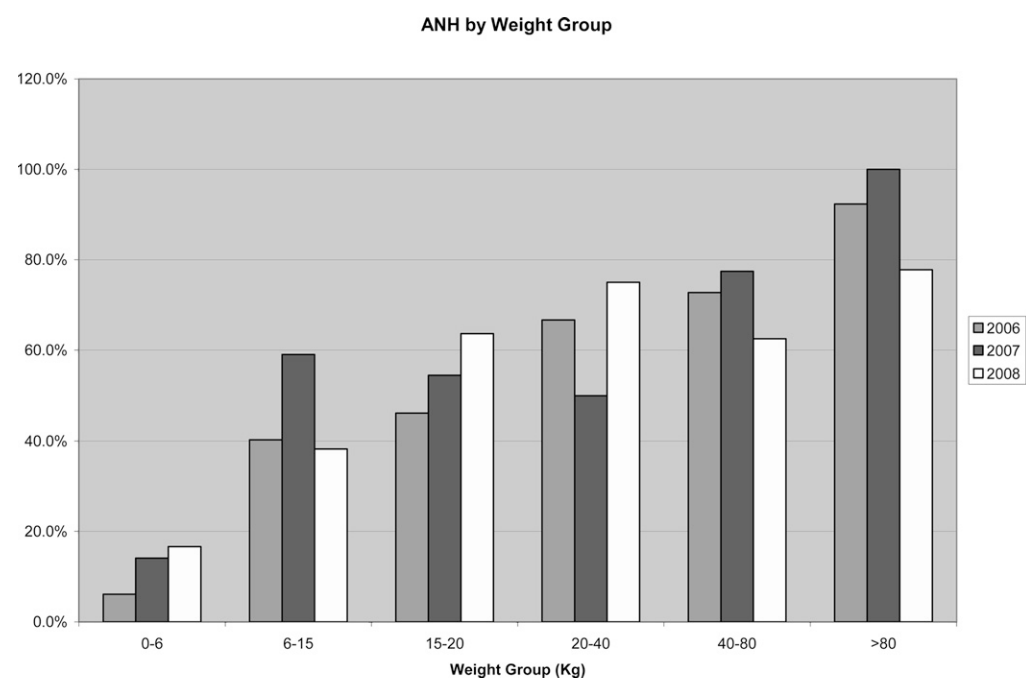

Figure 1. Percent of patients undergoing acute normovolemic hemodilution by weight group and year.

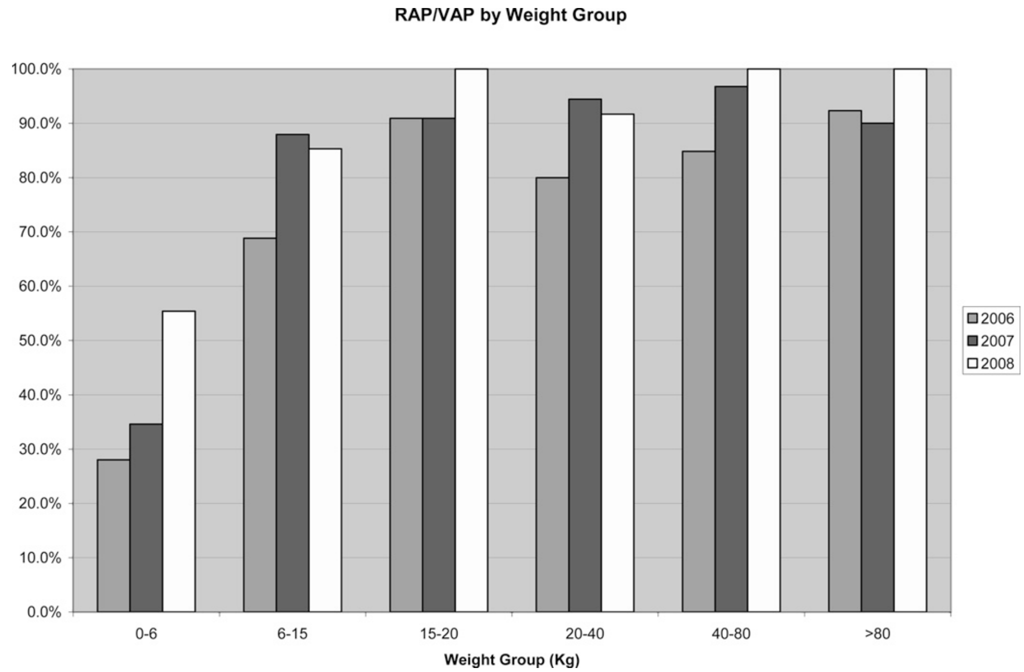

Figure 2. Percent of patients undergoing retrograde arterial prime and venous antegrade prime by weight group and year.

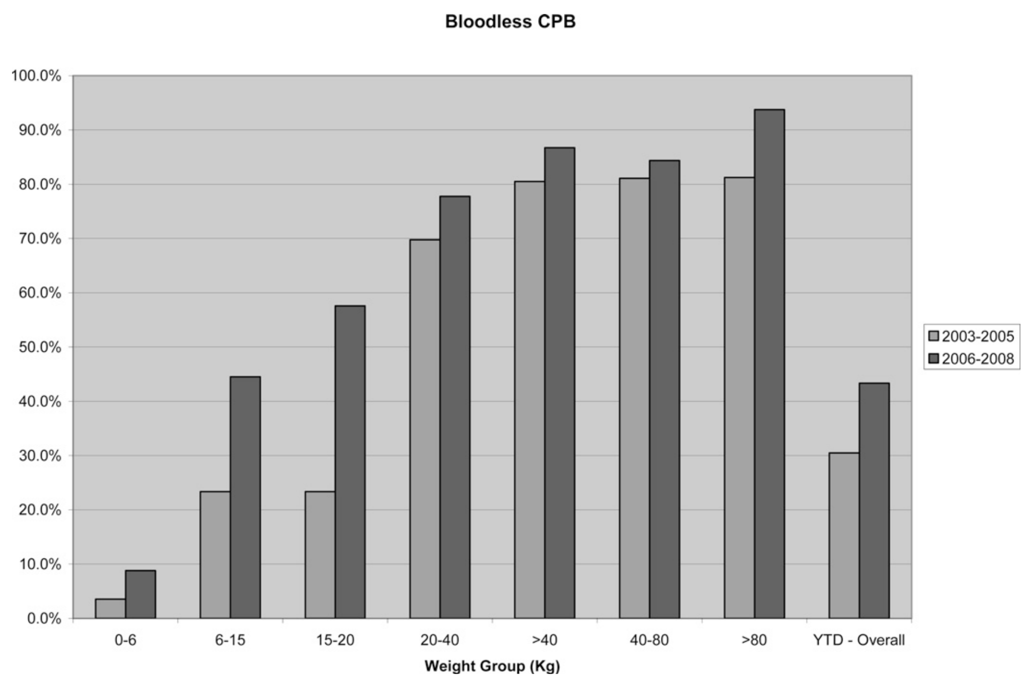

Figure 3. Percent of patients undergoing bloodless open-heart surgery in the OR by weight group.

accomplished bloodless surgery in neonates 3–5 kg, including arterial switch procedures, comprehensive stage II for hypoplastic left heart syndrome, and heart transplants. It is within the group of infants ≤5 kg that is the most challenging and difficult to accomplish without blood. Hübler et al. have reported transfusion free CPB procedures in patients of 1.7 and 2.2 kg with the use of mast mounted pumps, which were remarkable accomplishments (10,13). While hardware may help with circuit miniaturization, it is possible to miniaturize with a traditional heart-lung machine and without the use of mast mounted pumps as we have done. Circuit selection, and thus, prime volume, is extremely important and must take into account the "total" circuit prime volume, including the cardioplegia/ultrafilter/

MUF circuit. Tubing diameter and length, including the position of the pump, oxygenator, and circuit, relative to the table, patient, and surgeon, is significant and may contribute to overall circuit prime volume more than the oxygenator selection. The two smallest circuits we used (1/8 × 3/16 and 5/32 × 1/4) are without an ALF secondary to the amount of hemodilution added. This is becoming less of an issue with the introduction of the new Terumo FX (Terumo Cardiovascular, Ann Arbor, MI) series oxygenators, which incorporate an arterial screen filter around the oxygenator fiber bundle without adding additional prime volume.

The transfusion of allogeneic blood is associated with increased morbidity and evidence implicating the potential of allogeneic blood as an instigator of inflammation (1–3,16,17). Between the potential of inflammation from blood, and that from cardiopulmonary bypass, it is imperative that circuit miniaturization is optimized for the individual patient to reduce inflammatory response. The use of ultrafiltration during and after CPB to potentially reverse the effects of both of these potential triggers should be considered for all patients (18).

The use of ANH in the OR, and RAP/VAP are not easily accomplished, especially when applying the technique to neonates. Murayama et al. have shown that pre-operative and intraoperative blood donation is safe for pediatric cardiac surgical patients, but this was for patients 5–10 years of age (19). It is imperative that the perfusion-anesthesia-surgeon team work closely together, and communicate for these techniques to work safely and effectively. Fluid administration needs to be kept to a minimum. Blood removal needs to occur slowly and cannot be forced or rushed. If blood removal needs to occur by withdrawal with a syringe, and occurs too quickly, the platelets may be activated. If RAP/VAP are not being tolerated, or cannot be performed because of patient instability, initiation of bypass must be performed slowly until the circuit is completely blood filled to avoid overwhelming the coronary arteries with crystalloid causing arrhythmias.

The scope of this preliminary study did not include postoperative markers of outcomes for the groups and time periods involved. From reports to the Society of Thoracic Surgery Database, the mean Aristotle Complexity Score for June 2004 through July 2008 for all patients was 7.7, with a discharge mortality rate of 3.4% (20). Additionally, a recently published study from this institution showed the results of early extubation after pediatric cardiac surgery with patients from the same period of time, 2003–2007 (21). Of the 391 neonates and infants less than 1 year of age between 2003 and 2007, 27% of the neonates and infants <3 months of age, 68% of infants 3–6 months, and 79% of infants 6–12 months were extubated by anesthesia; 221 in the OR and seven in the intensive care unit (ICU). There were no deaths in the extubation group, although six (<3%) required re-intubation in the ICU, 2% required nasal CPAP (continuous positive airway pressure), 1% face mask, and 1.3% nasal or oral airway. The mean lactate by group was 2.47 mmol/L for the neonates 0–3 months, 1.73 mmol/L for the 3–6 month group, and 1.82 mmol/L for the 6–12 month old group.

CONCLUSION

Blood administration is never without the risk of consequence. As such, it is desirable to attempt to reduce or eliminate allogeneic blood product transfusions. More families and patients are becoming aware of the long and short term risks associated with the administration of blood and are asking for bloodless techniques even if it is not a religious preference. The application of a number of techniques that are also used and recommended for adult cardiac surgery can be applied to pediatric open-heart surgery patients (22). Bloodless open-heart surgery can be performed and sustained in a tertiary pediatric cardiac center.

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